Analysis of Robustness Sliding Mode Control Method for Active Suspension System

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Abstract

Taking vehicle transport into consideration, there are major systems that play important roles from the road to the body of the car to ensure the comfortability of the passengers. For that matter, the goal of car manufacturers is to develop the best suspension systems to guarantee this. In this article, active suspension system using a model of slide controller has been introduces with the purpose of advancing the comfort zone and accelerating vertically on passengers in the car. Based on ¼ models of extraction system and the mode control sliding coefficient using linear equations to minimize maximizing of time setting and exceed for upright acceleration on a passenger have been enhanced and resolute by means of ICA evolutionary algorithm. The proposed controller has been presented from experimental results through simulation for improving system constancy to progress the passenger luxury region. Evaluation of simulation results acquired through the suggested controller with the aid of the passive mode indicates the enhancement in passenger comfort in addition to the constancy parameters.

Keywords

Introduction

Considering the most significant systems in cars, suspension system plays an indispensable part in comfortability of passenger and the stability of the car. From the market desire and manufacturing car technologies, Semi – active and active suspension systems has interchanged the dampers and passive springs. In previous few years, numerous researches have been completed for improvement of the functionality of active suspension system. Some of the groups of researchers including "Supavet" projected a robust adaptive controller aimed at the suspension system [3]. David Brown with his associates demonstrated an intelligent controller an adaptive control for suspension systems in 2008 and "Zhang Shan Lee" and his associates introduced a nonlinear control algorithm in 1995 [2]. Among the scholars who have worked on the active suspension system, can note the colleagues with David Brown In 2008, they introduced an intelligent controller an adaptive control for suspension system [1]. Zhang Shan Lee and his colleagues (1995) proposed a nonlinear control algorithm [2]. Also, in 1999, Supavet introduced a robust adaptive control for the suspension system [3]. If a suspension system is rigid, luxury of the passengers restricts and its value would be objectionable. For that matter, the supplementary upright force that is produced by indiscretions in the road, shall transfer to the life in the car. Once the car is in motion using a rigid suspension system, the passengers are capable of feeling an uncomfortable ride. On the other hand, this sort of suspension system makes the car extra steady on the road. As a result, the designing the suspension system is a concession among these two parameters. Passive suspension system can advance the comfortability of passengers, but then again will not be able to fulfill concession between these two parameters. The active suspension system may concurrently control two parameters. By so doing, it can begin a compromise between the two parameters. [4]. In this article, principally, Based on ¼ models of extraction system and the mode control sliding coefficient using linear equations to minimize maximizing of time setting and exceed for upright acceleration on a passenger have been enhanced and resolute by means of ICA evolutionary algorithm. By the use of the ICA algorithm, the coefficient of mode controller sliding has been optimized and explaining a cost purpose for the algorithm.

System of Car Suspension Using Model ¼

As shown in Figure 1, there is an active suspension system by the use ¼ models with two degrees of independence. Undoubtedly, model ¼ is among the

best efficient models for evaluating the suspension system and is presented grounded on model ¼ of wheel. We presumed that the tyre is in touching base with the surface of the road which by so, is replicated by a spring and non-spring mass. Linear equations for suspension system are proven by Equations 1 and 2:

$$m_s \ddot{z}_s = -k_s(z_s - z_u) - b_s(\dot{z}_s - \dot{z}_u) + f_a \quad (1)$$

$$m_u \ddot{z}_s = k_s(z_s - z_u) + b_s(\dot{z}_s - \dot{z}_u) - k_t(z_u - z_r) + f_a \quad (2)$$

In which z_u is the displacement of the wheel (m), k_s is rigidness of the suspension spring (N/m), k_t is rigidness of the tyre (N/m), f_a is applied force on the body (N), m_s is the mass body of a quarter, m_u is mass of wheel (kg), b_s is the coefficient of the damper (Ns/m), z_s is the displacement of the body (m) and z_r is the entrance of the road (m).

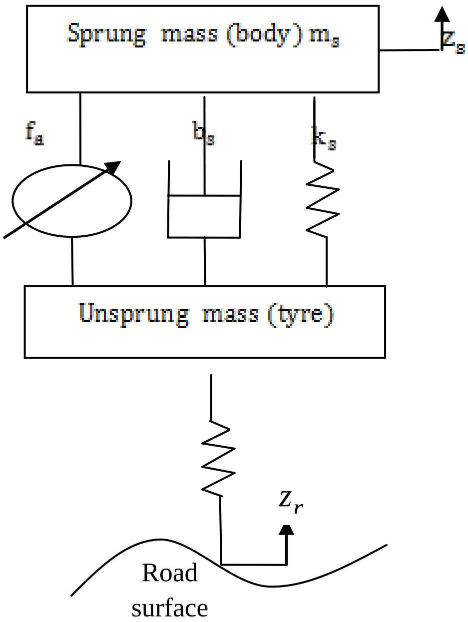


FIGURE 1 SYSTEM DESIGN OF THE MODEL

The stated variables are $\begin{cases} x_1 = z_s \\ x_2 = \dot{z}_s \\ x_3 = z_u \\ x_4 = \dot{z}_u \end{cases}$

By means of the equations 1 and 2, from the definition of stated variables as indicated, and equations of state space is possible to be attained from equations 3 to 6:

$$x_1 = x_2 \quad (4)$$

$$x_2 = \frac{F_a}{m_s}x_3 - \frac{bs}{m_s}x_4 - \frac{bs}{m_s}x_2 - \frac{K_s}{m_s}x_3 - \frac{K_s}{m_s}x_1 \quad (5)$$

$$x_4 = \frac{F_a}{m_s} - \frac{bs}{m_u}x_4 - \frac{bs}{m_u}x_2 - \frac{K_s}{m_u}x_3 + \frac{K_s}{m_u}x_1 - \frac{K_t}{m_u}x_3 + \frac{K_t}{m_u}zr \quad (6)$$

According to the definitions above, state matrices can be determined as follows:

$$\dot{x} = Ax + B\begin{bmatrix} f_a \\ z_0 \end{bmatrix} \quad (7)$$

$$A = \begin{bmatrix} 0 & 1 & 0 & 0 \\ -\frac{K_s}{m_s} & -\frac{bs}{m_s} & \frac{K_s}{m_s} & \frac{bs}{m_s} \\ 0 & 0 & 0 & 1 \\ \frac{K_s}{m_u} & \frac{bs}{m_u} & -\frac{K_s}{m_u} - \frac{K_t}{m_u} & -\frac{bs}{m_u} \end{bmatrix} \quad (8)$$

$$B = \begin{bmatrix} 0 & 0 \\ \frac{1}{m_s} & 0 \\ 0 & 0 \\ \frac{1}{m_u} & \frac{K_t}{m_u} \end{bmatrix} \quad (9)$$

Road Model

According to active suspension studies, taking model into consideration for the road is very significant. Researchers practice numerous models to simulate road model which two of the common models are as follows:

Model 1: As indicated in Figure 2, the road entry measured as a half-sine signal provided in 1997 by "Jung-Shan Lin". Equation 10 is used to simulate and study control system [4].

$$\begin{cases} a(1 = \cos \omega t) & 1.25 \le t \le 1.5 \\ 0 & otherwise \end{cases} \quad zr = \quad (10)$$

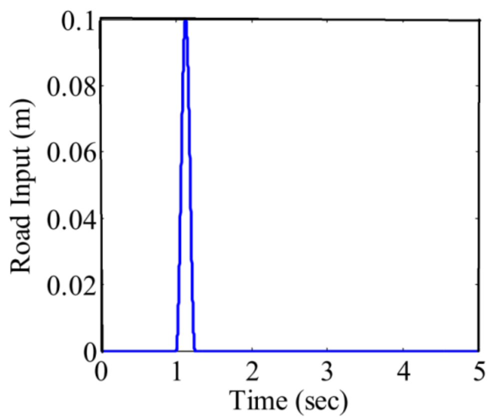


FIGURE 2 BUMPING OF THE ROAD

Model 2: This technique is centered on Power Spectral Density theory in which the road entry measured as to the state variables according to equation 11 [5].

$$\dot{z}_r = -2\pi f_0 z_r + 2\pi\sqrt{G_0 U_0 \omega_0} \tag{11}$$

Where the rigidity standards are represented as G_0, lower cutoff frequency as f_0, entry of road as z_r, and coefficient of Gaussian white noise is represented by ω_0 the entire entries will not be able to indicate every real levels of the road.

Rivalry Colonial

Mainly, the algorithms for optimization is motivated by the natural practices whiles other features of human evolutions are not well-thought-out from these algorithms therefore in our research, an improved has been introduced, whereby human phenomenon does not affect it but rather phenomenon of socio-humanity. To emphasize on one point, colonization procedure as a period of socio-historical evolution of human has been taken into consideration and from the historical singularity model, it has been used as a source of motivation for a prevailing optimization algorithm. Figure 3 illustrates the block diagram of our proposed algorithm.

Designing Controller

During modeling, inexactitudes in the model of the system could be according to doubts in the parameters of the system, or be according to the focused collection of a streamlined view of the dynamics of the system. As a result, according to the control, the lack of accurateness during the model design is possible to be categorized into two main types:

- Hesitation of the structure
- Doubts of Non-structural (non-modeled dynamics)

The principal kind of indecision is associated to inexactness in terms of the model while next one is associated to inexactness in the directive of the system. Inexactitudes in modeling may have an adverse outcome on the system and especially has unwanted effects on the non-linear system. A key and corresponding technique to handle the vagueness of the model is by means of a robust control which has been elucidated in this part of the paper. According to this paper, the projected nonlinear sliding mode controller structure is entailed of a trifling section and numerous additional terms to manage the uncertainties of the model. Sliding mode controller is mostly used in systems which need to keep stability and unchanging system routine with estimated model legally. Similarly, the controller can also be an optimal controller for systems having hesitation in parameters and non-modeled dynamics. One delinquent behavior with this controller is the controlling of energy consumption; so our other motive is to reduce the amount of energy consumed using colonial competitive optimization algorithms. The feedback of this system with a controller has been illustrated in figure 4.

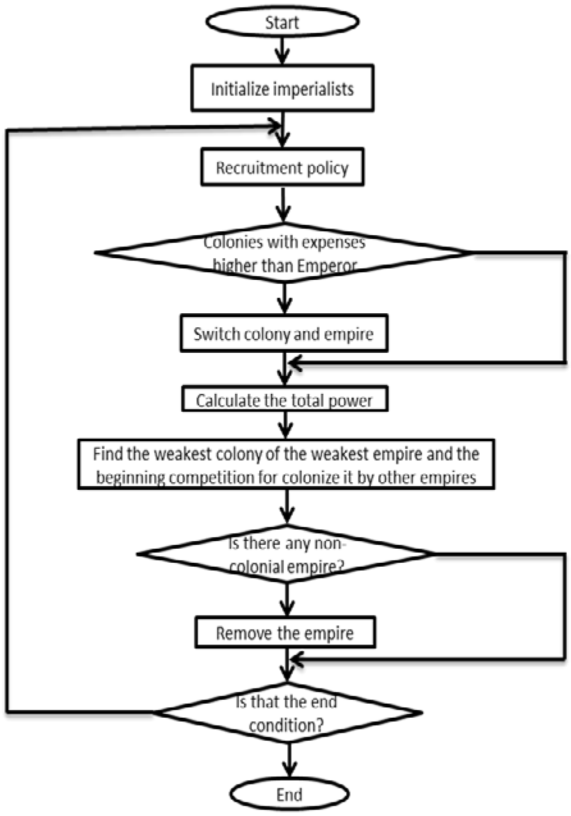


FIGURE 3 ALGORITHM RIVALRY COLONIAL BLOCK DIAGRAM

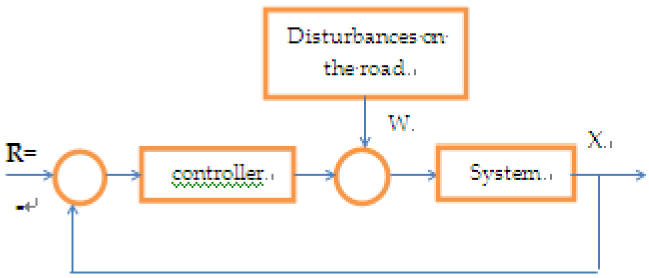


FIGURE 4 CLOSED LOOP

The controller entails of two parts: the switch and the controller: the rule for control and the rule for the switch. Comparable rule for control: Sliding surface is distinct using the equation:

$$S(t) = \left(\frac{d}{dt} + \lambda\right)^{n-1} \tag{12}$$

Where n is order of system and λ is a positive number. The order of system is 2. Therefore, we can deduce equation 13 from equation 12 as:

$$S(t) = \left(\frac{d}{dt} + \lambda\right)^{1} e = \dot{e} + \lambda e \quad (13)$$

where e indicates the error in the system. Using the derivative of the sliding surface and replacing equations 1 into equation 4, rule of the control is obtained by:

$$f_{eq}(t) = \ddot{x}_R - b_s x_4 + b_s x_2 - k_s x_3 + k_s x_1 - .\frac{(x_1 - \dot{x}_R)}{m_s} \quad (14)$$

In other for the control rule to be more robust, sign function should be added to it. Lastly, the last control rule can be obtained as :

$$f = f_{eq} - k\,\mathrm{sgn}(s) \quad (15)$$

According to the theory proposed by Lyapunov for the stability, every system has a Lyapunov function known as V as to if the derivative of this function is a negative figure, the system will be steady. For control in sliding mode, the Lyapanov function will be:

$$V = \frac{1}{2} S^2 \quad (16)$$

$$V = \frac{1}{2} S\dot{S} \quad (17)$$

$$\dot{S}(X,t) = \ddot{x}_1 - \ddot{x}_R + \lambda(\dot{x}_1 - \dot{x}_R) \quad (18)$$

Here by, substitute equation 18 into equation 16 and you will obtain:

$$V = \frac{1}{2} S(-ksng(S)) \quad (19)$$

Taking equation 19 into consideration, the system is now stable.

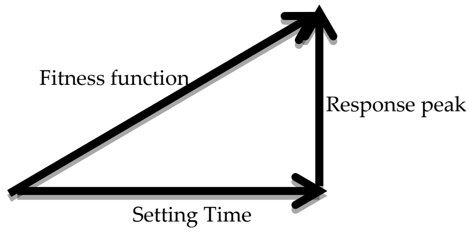
Coefficients Calculation

Considering the cost function, the time to settle and the system maximization overshoot for system response to the entrance of the road, is minimum value. For the designing of the sliding controller, researchers have made use of different objective functions in evolutionary algorithms. Typically minimum value is correspondent of the objective function; the optimization values of design controller parameters are deduced. The cost function used is grounded on minimization of Integral Absolute Error (IAE), Integral Time Absolute Error (ITAE) and Integral of the Square of the Error (ISE) for different value. Our cost function is defined built n the maximum acceleration on car body and the time to settle which is measured as equation 21:

$$F = \sqrt{\omega(O_v^{\,2}) + S_t^{\,2}} \quad (20)$$

where O_v is the overshoot maximum and S_t is settling time.

In new idea that provided for the cost function, as showed in Figure 6, the settling time and peak time of response are two vertical vectors. The introduced objective function demonstrates the size of sum of these two vectors. In new objective function, so as to give weight to terms of objective function, the parameter ω is multiplied by settling time.



This indicates the vector relationship for equation 20 about.

mu(kg)	Ks(N/m)	Kt(N/m)	ms(kg)	Bs(Ns/m)
87.15	66824.2	101115	225	1190

Simulation Results

The simulation below shows the model of a ¼ active suspension system shown in figures 1 above with the parameters for the system used shown in table 1. In our algorithm, we considered the number of initial population to be 10 and the generation replication as 50 as indicated in figure 7 also showing the value of cost function in each period.

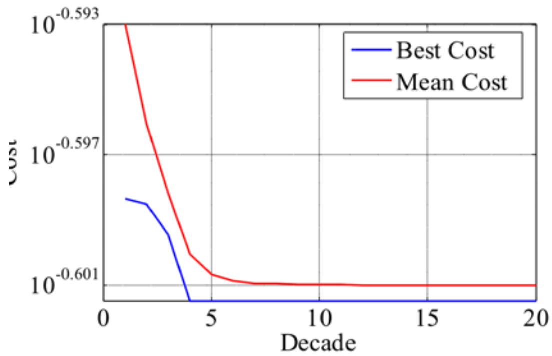


FIGURE 7 DECADE COST FUNCTION VALUE.

We have compared the parameters related to the travel stability of the active suspension and passive system in figure 8, 9 and 10. Also, we compared in table 2 the statists of the quantitative parameters. The acceleration vector of active system suspension for passengers has

been compared with the passive system in figure 8 and it has been reduced up to 7 times.

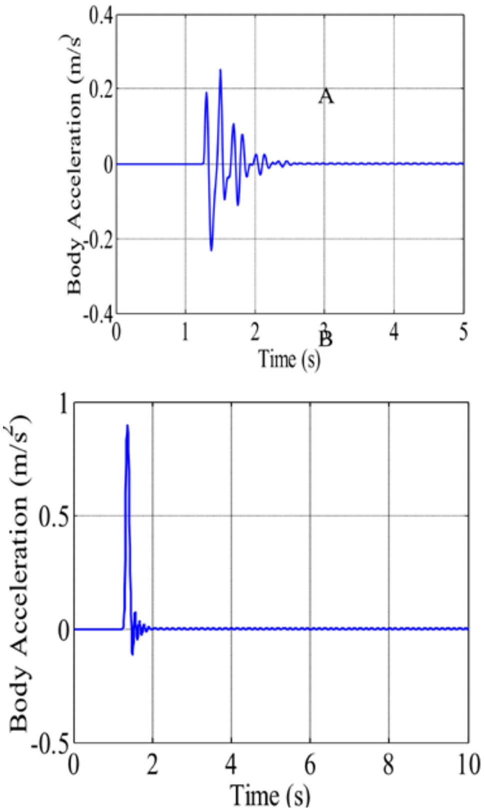


FIGURE 8 THE ACCELERATION ON CAR BODY. (A) ACTIVE (B) PASSIVE

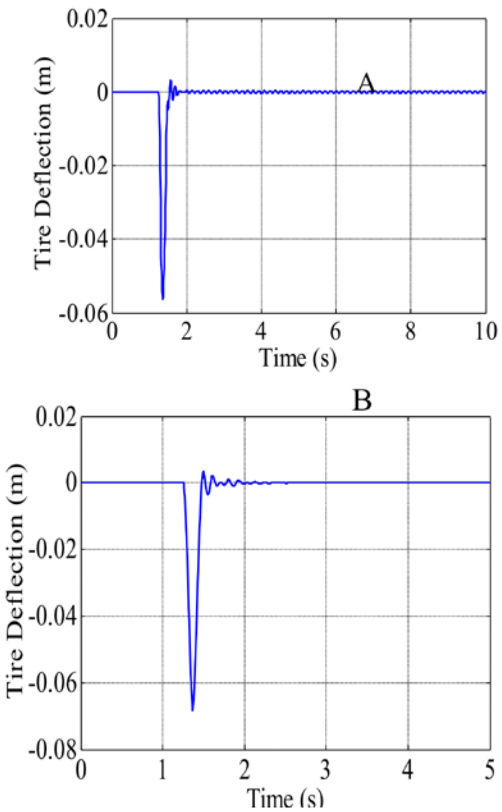


FIGURE 9 SIMULATION OF ROAD SURFACE WHEEL OFFSET. (ACTIVE AND PASSIVE RESPECTIVELY)

Again, in figure 9, the active suspension for the safety of the car in which we reduce the wheel offset of road has been improved for suspension system stability. The relative displacement which has relations to the stability of the suspension system is shown in figure 10. Compared to passive mode, the active mode is improved.

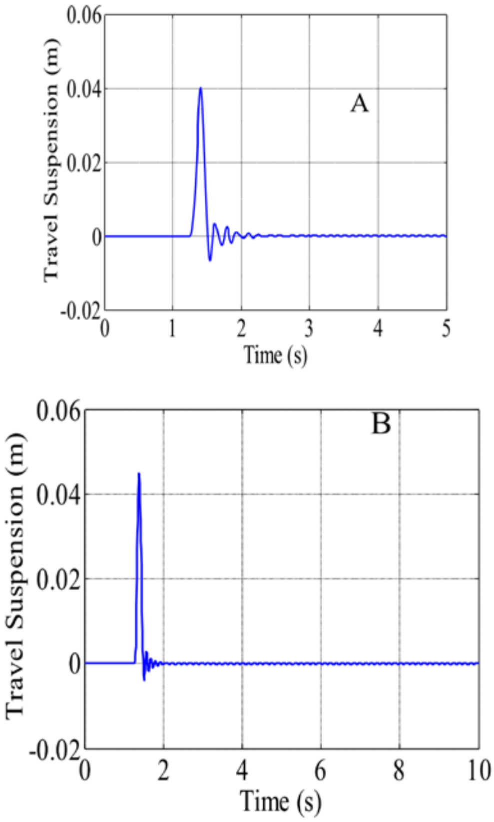


FIGURE 10 RELATIVE DISPLACEMENT

Conclusions

Linear model ¼ mode of sliding controller has been introduced in this article for active suspension system, having excellent results for vertical acceleration which acts on the body of the car. And also the coefficients of controller using ICA evolutionary algorithm has been determined. Series of experiments were simulated and results were recorded with improvement of passenger comfort parameters in active mode equated to passive mode. Similarly, the parameter road surface car stability which is related to the relative displacement directly and offset of the wheel, in active mode using the suggested controller in ICA technique is upgraded equated to the passive state.

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